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MINERALOGICAL EXAMINATION OF TAILINGS FROM THE HEATH STEELE MILL, NEWCASTLE AREA, NEW BRUNSWICK

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Tailings Characterization and Treatment

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MICROMEDIA

MINERALOGICAL EXAMINATION OF TAILINGS FROM THE HEATH STEELE MILL,
NEWCASTLE AREA, NEW BRUNSWICK

by

J.L. Jambor and D.W. Blowes

ABSTRACT

Sulphide-rich tailings in the oldest of the impoundments at the Heath Steele minesite, Newcastle area, New Brunswick, consist of about 90% sulphides (by volume), accompanied by quartz and minor amounts of magnetite, muscovite, chlorite, gypsum, and only traces of other silicates. Nearly all of the sulphide component is pyrite; minor amounts of pyrrhotite, chalcopyrite, and sphalerite are accompanied by sparse galena, arsenopyrite, and tennantite-tetrahedrite. The near-surface ~30 cm of core is the lightest in colour, possibly because of a high content of pyrite and quartz; this zone is succeeded downward by a covellite-enriched zone, 15-20 cm in thickness, which shows the highest intensity of alteration of pyrrhotite. This intensity, however, is only moderate in absolute terms: most alteration has not advanced beyond the formation of rims on grains, and few pseudomorphs or mere residual cores are present. Tailings beneath the covellite zone show little evidence of alteration. Within the tailings pile is a near-surface, thin, cemented layer in which the binding agent is predominantly melanterite, $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$. Iron oxides/oxyhydroxides, which typically form by oxidation of sulphides, have not been observed in the core samples (except for local paleosurface oxidation). The pore

waters are highly enriched in sulphate and iron which, upon drying of the core, crystallize predominantly as melanterite and later $\text{XSO}_4 \cdot n\text{H}_2\text{O}$ phases that solidly cement the cores.

Keywords: sulphides, tailings, alteration, sulphates, covellite, hardpan, Heath Steele, Wedge mine, New Brunswick.

INTRODUCTION

The Heath Steele minesite is about 51 km northwest of Newcastle, New Brunswick. The exploited orebodies are of the massive sulphide type, and consist of a lead-zinc ore hosted predominantly by pyrite, and a copper-rich ore in which the main iron sulphide is pyrrhotite. Production began in 1957, but periodic shutdowns have occurred; the longest relatively uninterrupted run was from 1969 to the mid 1980's, during which production was mainly at 3000 to 4000 t.p.d. Mill tailings were deposited in two impoundments, the older of which was examined by Boorman & Watson (1976), and ten years later the pore gas, pore water and tailings solids were resampled by D.W. Blowes of the Waterloo Centre for Groundwater Research, University of Waterloo.

As part of a comparative study of cemented layers in the tailings at Heath Steele and at Waite Amulet, Quebec, ten samples of the Heath Steele tailings intersected in hole OW-8, which is closely adjacent to site 8 examined by Boorman & Watson (1976), were shipped by courier from Waterloo to CANMET for mineralogical study. The tailings samples, each in its aluminum-pipe core-barrel, had been frozen on-site at the time of collection, and were stored frozen at Waterloo. The cores are approximately 7.6 cm (3 ins.) in diameter, and each sample represents a depth interval of 15 to 20 cm. Prior to shipment to CANMET, the cores were sawn along the length so that half could be retained at Waterloo. The orientation of the cores was marked on the barrel,

and each sample was assigned a number that increased with the down-hole progression; the cores received are C1 to C7 inclusive, and C10, C11 and C12.

RESULTS

The cores as received were in excellent condition: except for the ends of two cores at the top of the insulated container, all material appeared to be frozen solidly. The ends that showed signs of thawing were wet on surface, but as this wetness was found to be only surficial on a solid substrate, the indication is that defrosting was not penetrative.

After storage in a freezer for three days the cores were removed for unfreezing at room temperature; the wrapping material and aluminum core-barrel containers were discarded after ejection of the solid cores into labelled, plastic-lined boxes. As thawing progressed, and as the cores dried, the following significant features were observed:

1. Within the core sequence the uppermost part is the lightest in colour; specifically, all of C1 and the upper half of C2 are brassier in appearance. The bottom half of C2 is the transition zone to the "normal" darkness (dark grey to black) of the remaining cores.
2. The free-moisture content of the cores was highest in the deepest cores (C10, C11, C12) and lowest in the shallow cores (C1 to C5 inclusive).

3. Surficial melanterite crystallized on ores C11 and C12 even in the presence of copious liquid.
4. Cores C1 to C5, and C7, dried without undergoing any significant physical change, and remained more or less intact. In contrast, cores C6 and C10-C11-C12 partly collapsed outwards (sideways) while drying; as a consequence, deep vertical tension cracks were formed along the length of the cores.
5. The Waite Amulet cores are fragile -- they lack cohesion and, for the most part, disintegrate readily when dried. Heath Steele cores not only remain intact, but are cohesive; samples C6 and C10-C11-C12 are especially strongly cemented.
6. White to very minor yellow sulfate blooms eventually form on the surfaces of all of the dried cores, but the blooms are especially profuse on samples C6 and C10-C11-C12.

Microscopic examination

Portions of the almost dry cores were removed with a utility-blade knife by cutting successive slices along the vertical (elongation) axis. The material removed in this way generally amounted to a third or half of the core, and the remainder has been kept intact. The sampled portion was screened to minus 270 mesh, and a portion of the powder from each sample was mounted in polished and polished thin sections. Because all cores except C7 have been divided in this laboratory into top and bottom halves, the number of samples selected was seventeen. Reflected-light microscopic study showed the following:

1. The proportion of sulphides in each sample is extremely high, probably exceeding 90% by volume. Almost all of the sulphide is pyrite, typically with a few per cent pyrrhotite, and less than 1% sphalerite plus chalcopyrite. In core C7 the non-sulphide content is negligible.
2. The lighter, brassier colour of the tailings at the top of the borehole seems to reflect (a) a high content of pyrite with no more than a trace of pyrrhotite, and (b) a predominance within the non-sulphide fraction, more so than in the other cores, of grains that are colorless to white.
3. Except for their presence in C12, secondary iron oxides or oxyhydroxides were not observed. In C12 a few paper-thin goethite-bearing orange-brown layers occur over a depth interval of about 2 cm. The goethite-bearing laminae are amidst finely bedded unaltered sulphides, and are interpreted to be paleosurfaces at which oxidation occurred during a hiatus in tailings deposition.
4. Although a few grains of covellite were observed in sample C1, the rare grains of pyrrhotite in the sections are unaltered, and no other signs of alteration are conspicuous. As a further check on the degree of alteration, a hand-magnetic fraction was separated from each of the top and bottom portions of C1. Examination of these separates in polished sections showed that about 75% of the grains are magnetite, and nearly all of the remainder is pyrite. The trace amounts of chalcopyrite and pyrrhotite in the sections

are unaltered. The conclusions are, therefore, that the pyrrhotite content of sample C1 is negligible, and that signs of in-situ replacement of sulphides also are negligible.

5. Starting at sample C2T (for all samples T designates the stratigraphic top half of the core, and B the bottom half), covellite is relatively common both as isolated grains (pseudomorphs?) and a rim and penetrative replacements of pyrrhotite. This covellite-rich zone includes samples C2B and C3T; covellite, although still present in the next lower sample (C3B), has very obviously declined in abundance.
6. The principal manifestations of alteration are the presence of covellite and the partial replacement of pyrrhotite. Alteration is weak throughout the core, and is strongest in the covellite zone. This higher intensity of alteration is reflected not only by the relatively high abundance of covellite, but also by the presence of numerous alteration rims of sulphates and arsenates-sulphates around pyrrhotite. Moreover, partial replacement of some grains of sphalerite and chalcopyrite has occurred in the covellite zone, but only pyrrhotite has been affected where alteration is weaker.
7. Alteration to arsenate-bearing minerals seems to be restricted to the zone of alteration of highest intensity, i.e., the covellite zone.

8. Using the classification of grain sizes as outlined in Jambor (1987), comparison of the Heath Steele cores indicates that most of the samples are coarse-grained, but C6 is finer grained than those higher in the tailings pile; samples C10 and C12 are in the intermediate category (mainly fine-grained with disseminated coarse grains), and C11 is fine-grained. These observations coincide exactly with the behaviour of the cores during thawing and drying: free moisture was highest and longitudinal tension cracks were most pronounced in the finest grained cores, and these also are the most strongly cemented upon drying. The distribution patterns of some of the physical features of the cores are shown in Figure 1.

Other studies

To determine the nature of the non-sulphide fraction in the uppermost and lightest coloured part of the core, a split of each sample was subjected to heavy-liquid separation using methylene iodide (specific gravity 3.3); the float fraction still was found to contain an appreciable amount of pyrite, much of it as fine-grained free particles. SEM-EDX examination of free grains, and EDX-WDS X-ray maps of polished sections of the floats from the coarse-grained samples indicated that, based on 25 to 75 non-sulphide grains per sample, core C3T and others stratigraphically beneath it contain a more diverse mineral assemblage than does sample C1T. In sample C1T the proportion of quartz relative to muscovite seems to be high, and no other silicates were detected.

A significant observation in terms of pH buffering is that siderite was detected (by EDX) in samples C1T and C5T, manganese-rich siderite was detected similarly in sample C3T, and the presence of dolomite in sample C4B was confirmed by three Debye-Scherrer patterns of three hand-picked grains.

X-ray diffractograms of the floats from 8 samples are shown in Figures 2 and 3. Quartz and pyrite are the predominant minerals, and chlorite and muscovite are detectable in most samples. Gypsum is present in all samples, and in C11T there are appreciable amounts of an unidentified mineral whose most intense X-ray peak is at about $5.47\text{\AA}$ (ss in Fig. 2). The mineral is a water-soluble sulphate, as is indicated by its disappearance after wetting the sample with water (Fig. 3). A much smaller amount of this mineral appears in sample C1B, in which the presence of an iron sulphate was indicated by energy-dispersion analyses.

Aside from the soluble sulphate, the distribution of chlorite seems to be a significant variant among the samples. Sample C1B is the only one in which chlorite is not evident in the X-ray diffractogram, and among the other samples the proportion of chlorite is lowest in sample C2T. Thus the X-ray diffraction studies combined with EDX results indicate that: (1) chlorite is lowest in the uppermost samples; (2) the silicate mineralogy of samples C3T and C5T is considerably more diverse than that in C1T; (3) the above two differences may account for

the lighter colour of the uppermost zone, and for pore-water compositional differences related to dissolution of the complex silicates (such as amphibole) from the upper zone. This aspect requires quantification, preferably using image-analysis techniques.

Optical microscopy, SEM-EDX study, and Debye-Scherrer X-ray patterns indicate that melanterite and gypsum are the principal sulphate minerals in the samples. The melanterite, which seems to be of end-member or near end-member composition ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$), forms a pale green to colourless, glassy binding agent which is evident in samples in the field. The mineral is responsible for cementation of a near-surface tailings layer which Boorman & Watson (1976) referred to as the Hard Pan layer. They reported this layer to consist partly of iron oxides and hydroxides, but these types of minerals are not present in the cemented zone in hole OW-8.

A separate sample collected by D.W.B. as representative of the Hard Pan layer was examined at CANMET, and it too showed melanterite to be the cementing agent. After allowing the sample to dry in air, 3 polished sections were prepared from large, cohesive fragments of the "hardpan". Examination of these sections showed the presence of abundant sulphate, and the absence of secondary iron oxides-oxyhydroxides. These results confirm that melanterite and well-crystallized gypsum (Fig. 4) are the principal sulphates that crystallized in situ prior to drying of the cores. Although both of these minerals also were

precipitated during drying (Fig. 5 - 7) melanterite was found to be the sole megascopically conspicuous precipitate. Melanterite begins to crystallize while free liquid is present in the cores, and only much later during the final stages of drying is this sulphate succeeded by crystallization of lower hydrates; the late phases are also of the type $XSO_4 \cdot nH_2O$, specifically the hexahydrate and tetrahydrate. The corresponding iron-dominant minerals are ferroxahydrate ($FeSO_4 \cdot 6H_2O$) and rozenite ($FeSO_4 \cdot 4H_2O$), but most EDX analyses indicate that the compositions of the late precipitates are highly variable in Fe-Zn-Mg-Mn; within this quaternary solid-solution variation, Mn is typically no more than a minor component, whereas any of Mg, Fe or Zn can be the predominant cation in specific crystallites.

In addition to the $X^{2+}SO_4 \cdot nH_2O$ phases, two Al-dominant sulphates have been detected. Both of the Al sulphates occur in small amounts as late-stage, white to yellowish globules (Fig. 8), and one or both have been found to occur in the matrix of samples C-1, C-3 and C-12 (thereby indicating the probability of an unrestricted spatial distribution). Globules of one of the phases were mounted in polished section (Fig. 9), and two electron-microprobe analyses gave Al_2O_3 18.9, 20.0, Fe_2O_3 1.7, 1.3, SO_3 49.9, 49.0 wt.%, corresponding to an average of $(Fe,Al)_{2.00}(SO_4)_{3.09}$. With this formula ratio as a guide the Debye-Scherrer X-ray pattern was identified as that of alunogen, $Al_2(SO_4)_3 \cdot 17H_2O$. The other phase remains unidentified.

Other sulphates and arsenate-bearing sulphate minerals have been found only in small amounts, and only within the covellite zone (samples C2T to C3T, inclusive). Minute amounts of lead sulphate, presumably anglesite, occur at the edges of galena (Fig. 10). Sulphate-bearing alteration rims on pyrrhotite show a consistent pattern in which covellite typically is separated from the pyrrhotite core (Fig. 11). The intervening phase is a sulphate mineral that contains Cu as the predominant cation ($\text{Cu} > \text{Fe}$). Microprobe analyses indicate up to 6.1 wt.% As in the phase, but because of poor totals, the results must be regarded only as semi-quantitative. Traces of phosphate also were detected, suggesting that the phase has the general composition $(\text{Cu}, \text{Fe})(\text{SO}_4, \text{AsO}_4, \text{PO}_4)$. X-ray maps for an arsenic-rich grain are shown in Figure 12.

TAILINGS ACCUMULATION

The Heath Steele tailings impoundment from which core OW-8 was obtained was built up during 1957-1958 and 1962-1963. The mill was commissioned in January 1957 and operated until April 1958, during which period "chalcocite" ore was processed for the first 3 months, and lead-zinc ore subsequently (Archibald 1971). The shut-down from 1958 to 1962 was complete; thus, the lowermost part of the tailings pile should represent waste from the initial production period, and the upper part of the pile, as was intersected in hole OW-8, should be from the 1962-1963 production period. For the first six months of 1962 the mill operated at

680 tonnes per day (750 t.p.d.), but the ore was derived from the Wedge mine, a totally unrelated deposit about 15 km north of Heath Steele (Douglas 1965; Meyer 1966; Jambor 1979). For the remainder of the 1962-1963 period, the mill throughput was doubled to 1500 t.p.d. (1360 tonnes), with half from Heath Steele and half from Wedge. Overall, therefore, the bulk of the tailings in OW-8 may be from Wedge ore rather than from Heath Steele. The special significance is that the sulphides from Wedge contain little or no pyrrhotite (which could account for the low content of pyrrhotite in the tailings), but the Wedge ore contained amounts of tennantite well above that normally present in deposits in the Bathurst camp (J.L. Jambor, unpubl. data). Dissolution of tennantite rather than arsenopyrite is thought to have contributed a major part of the arsenic which is a component of the alteration phases that occur as rims around sulphides.

CONCLUSIONS

Core OW-8 is distinctly different from the cores that were obtained from the Waite Amulet, Quebec, sulphide-rich tailings: a major physical difference is that Waite Amulet cores are fragile and disintegrate readily, whereas the dried cores from Heath Steele are strongly cemented by sulphates that crystallized from the sulphate-laden pore waters. Other major differences are that the Heath Steele tailings contain a distinct covellite-rich zone (Fig. 1), but the tailings do not have an oxidized zone in which the sulphides were altered to iron oxides/oxyhydroxides, nor was

jarosite found in any of the samples from Heath Steele. The principal cementing minerals at Heath Steele are gypsum, ferrous sulphates in which there is some Zn-Mg-Mn solid solution, and alunogen. Within the tailings pile is a near-surface, thin, cohesive layer which was referred to by Boorman & Watson (1976) as the Hard Pan layer; the principal cementing phase in this layer is melanterite, $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$.

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- Fig. 1. Summary of some of the major features in core OW8. The melanterite-rich cemented layer occurs at a depth equivalent to that of sample C2.
- Fig. 2. X-ray diffractograms of the float fraction (S.G. <3.3) of tailings samples from Heath Steele. Sample numbers at far right correspond to the OW 8 sequence from surface (C1B) to depth C11T); HP is a separate sample of so-called "Hard Pan". Abbreviated mineral names are: py pyrite, q quartz, gy gypsum, ch chlorite, mu muscovite, and ss unidentified soluble sulphate.
- Fig. 3. X-ray diffractograms of sample C11T: untreated sample showing a strong peak (ss) for an unidentified mineral is at the bottom; upper diffraction pattern is for the same sample after addition of water and decanting to remove soluble sulphate.
- Fig. 4. Polished-section grain mount of hand-magnetic fraction from sample C1T. Backscattered-electron image shows pyrite grains (py) partly enclosed in a large crystal of gypsum (gy); one of the few grains of pyrrhotite (po) in this sample has a rim consisting of a mixture of covellite and iron sulphate.
- Fig. 5. Discontinuous, arborescent gypsum, extending from lower left to top right, precipitated on the tailings-grains substrate during drying of the core.

- Fig. 6. Crystals of iron sulphate (probably melanterite, m) with upright to bent, thick, hair-like grains of a Mg-Zn-Mn sulphate that probably is in the rozenite (tetrahydrate) or hexahydrate ($\text{MgSO}_4 \cdot 6\text{H}_2\text{O}$) group. These sulphates, as well as those in Figures 6 and 7, crystallized during drying of the core.
- Fig. 7. Hairlike crystals of Zn-Fe-Mn-Mg sulphate of the type $\text{X}^{2+}\text{SO}_4 \cdot n\text{H}_2\text{O}$, in this case apparently zinc-dominant, extending from the surface of core C11.
- Fig. 8. Surface of a globule of alunogen, showing masses of platy crystals. Sample C3B.
- Fig. 9. Backscattered-electron photograph of a polished-section surface of microprobe-analyzed alunogen globules, showing prominent shrinkage cracks and inclusions of iron sulphate (white) that probably are rozenite. Sample C1.
- Fig. 10. Galena (white) altered at its edges by lead sulphate (probably anglesite, PbSO_4). Sample C2T.
- Fig. 11. Backscattered-electron photograph showing pyrite (py) and pyrrhotite (po), with the latter partly rimmed by covellite (cv) and a darker grey, copper-bearing sulphate-arsenate phase whose distribution is evident from the X-ray map for arsenic (right; wavelength dispersion, $\text{AsL}\alpha$). Sample C2B.
- Fig. 12. Magnetite (m), pyrite (py), and pyrrhotite (po) in sample C2T; (a) backscattered-electron image; (b) X-ray map, $\text{AsL}\alpha$; (c) X-ray map, $\text{FeK}\alpha$; (d) X-ray map, $\text{CuK}\alpha$.

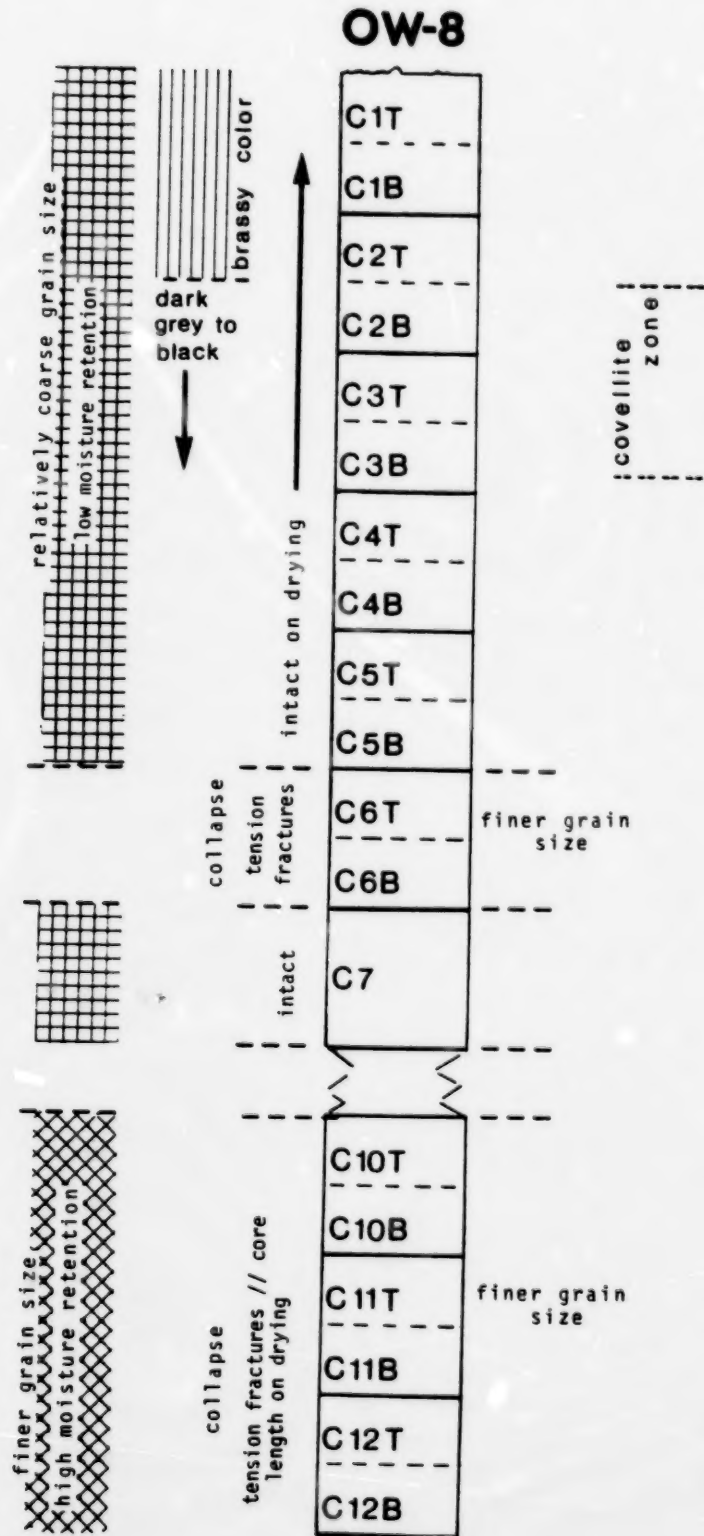


FIG. 1

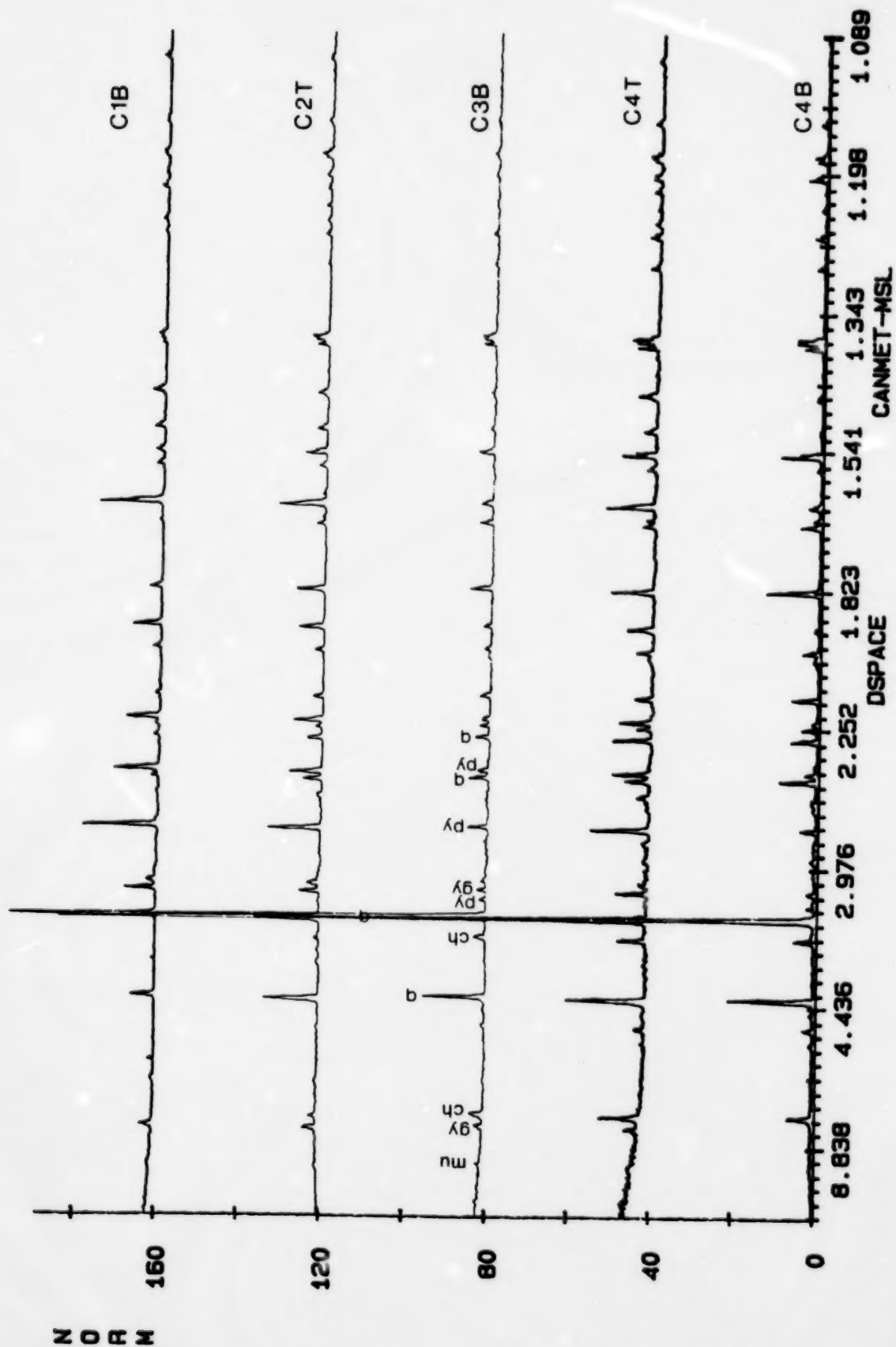


FIG. 2

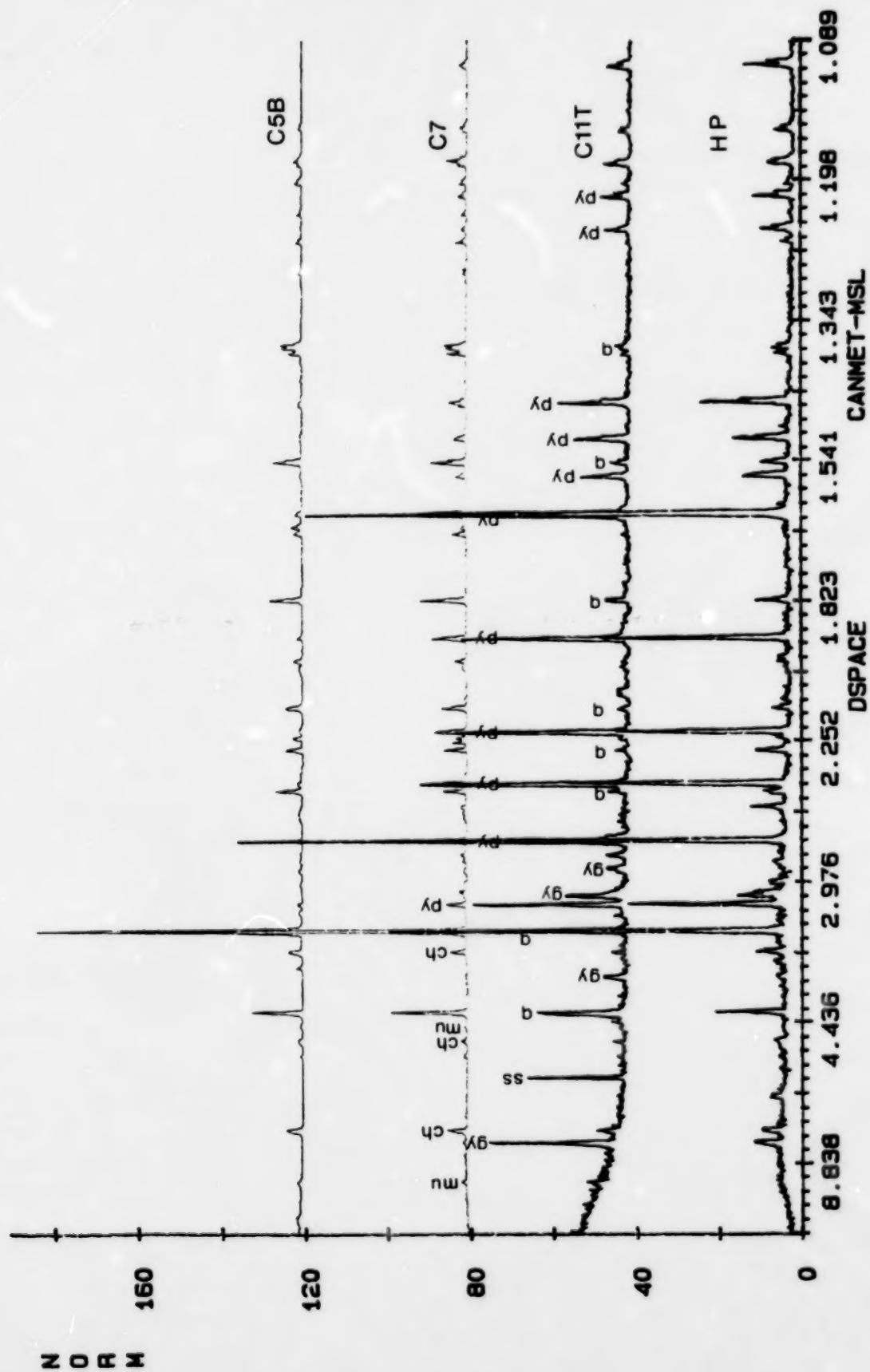


FIG. 2 (continued)

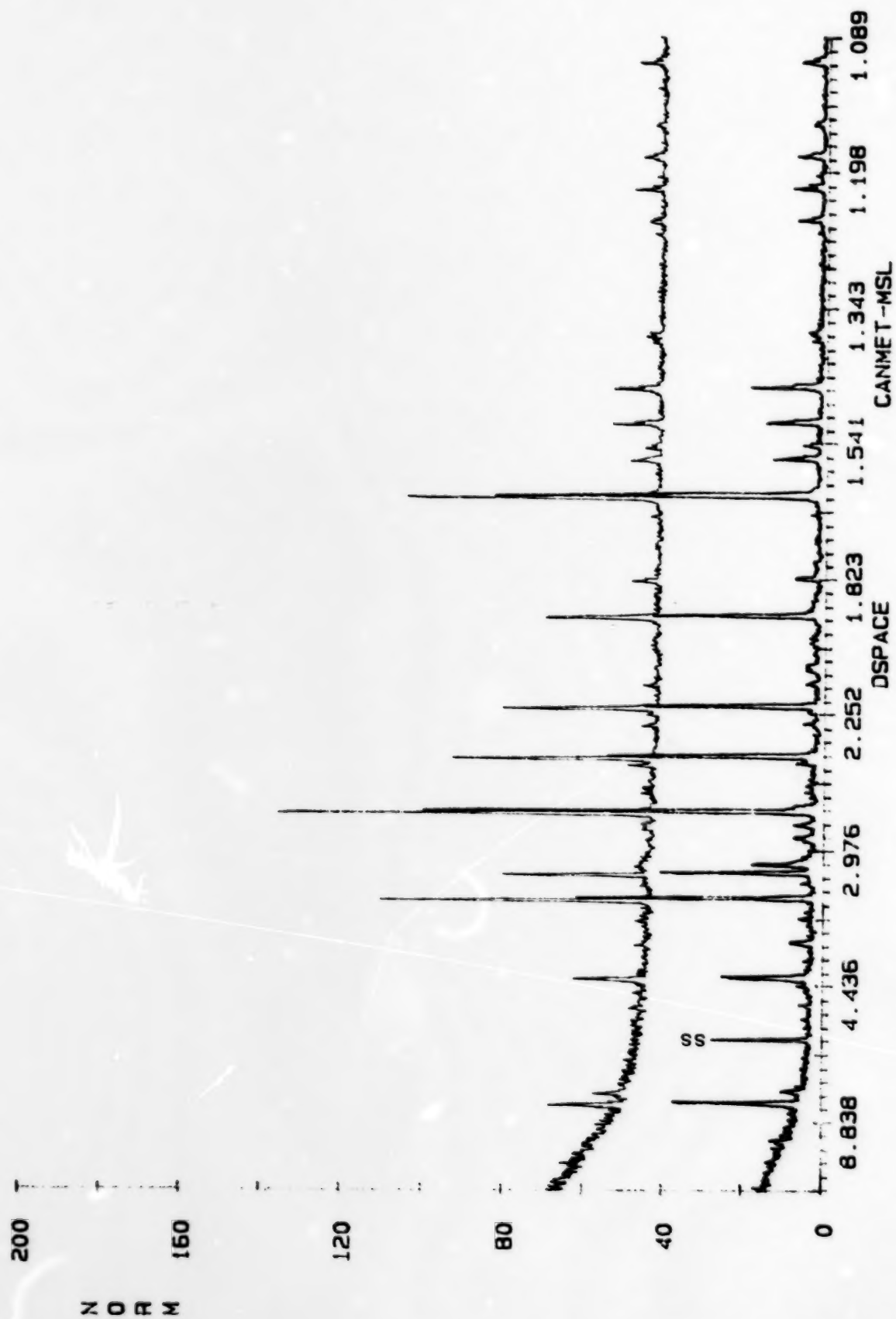


FIG. 3

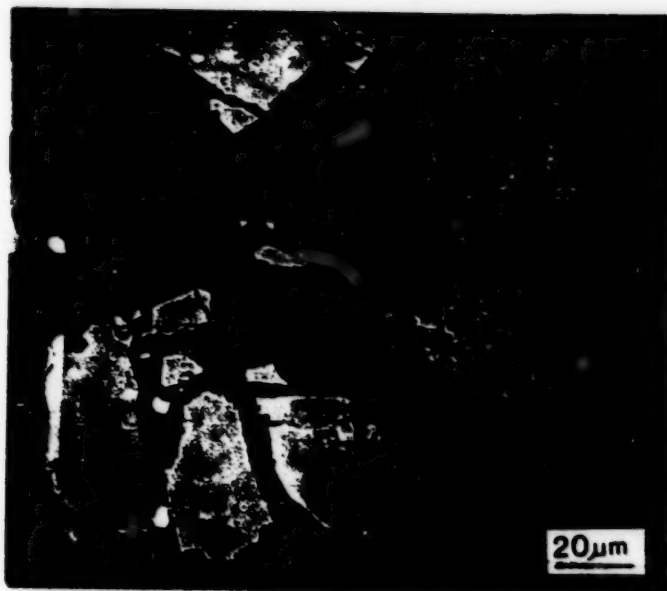


FIG. 4



FIG. 5

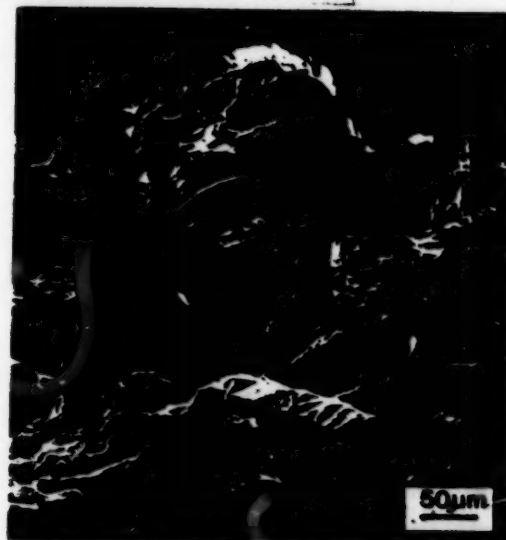


FIG. 6

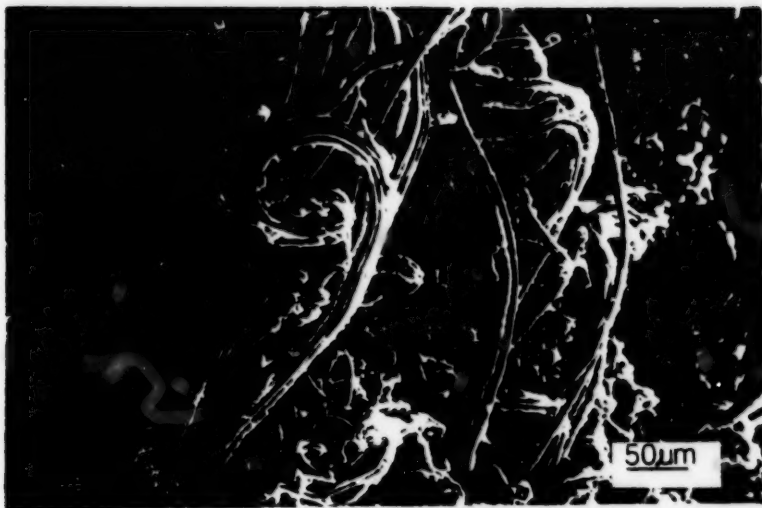


FIG. 7

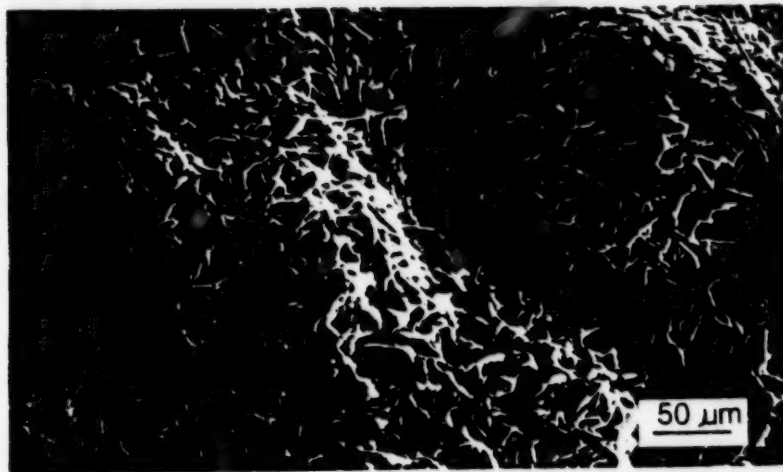


FIG. 8

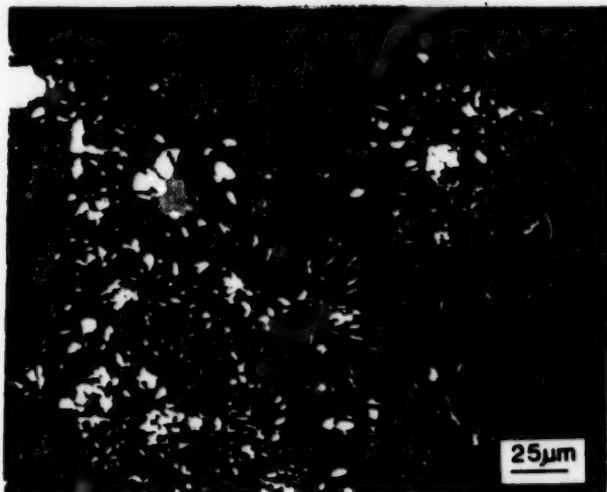


FIG. 9



FIG. 10

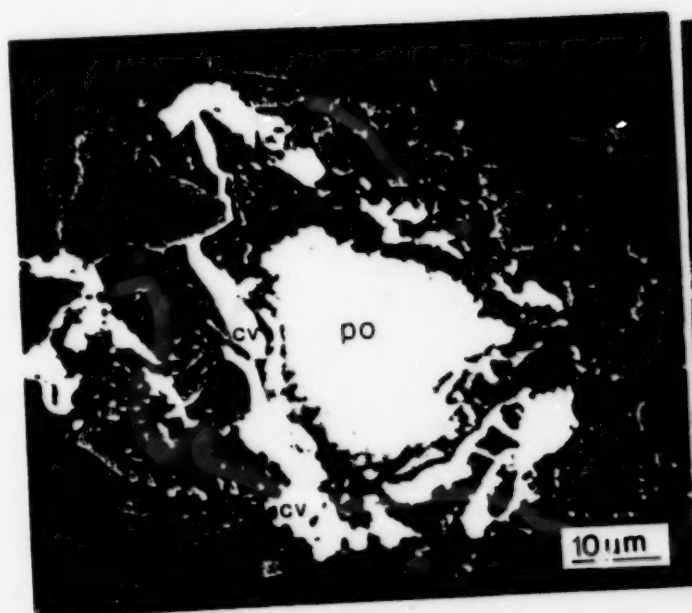


FIG. 11

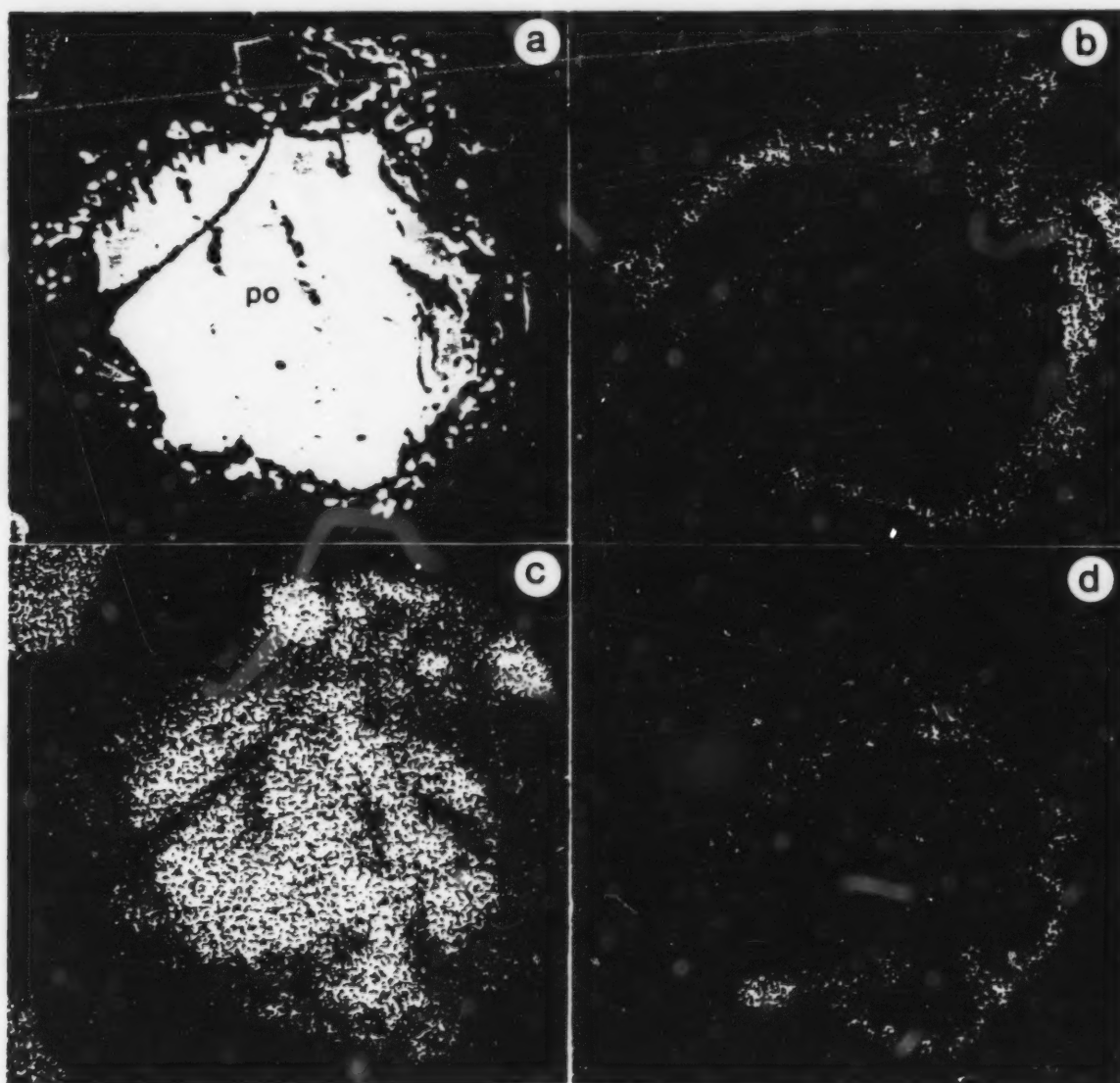


FIG. 12